Bioreactors of “Basket” Type with Immobilized Biocatalysts

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Abstract: The spectacular applications of the immobilized biocatalysts determined the design and construction of some proper bioreactors, specific or derived from the “classical” ones. Among them, the bioreactors with immobilized biocatalysts are some of the most studied and applied bioreactors. The biocatalyst could be disposed around the stirrer in a fixed bed with cylindrical geometry. This type of bioreactor is known as “basket bioreactor”. In this context, the aim of the paper is to briefly review the recent literature on the main types of the “basket” bioreactors with immobilized biocatalysts, from the viewpoint of their construction and applications, by analyzing their advantages/disadvantages comparatively to the other types of bioreactors.

Key-words: Bioreactor, Immobilized Cells, Fixed Bed, Basket Bioreactors

1 INTRODUCTION

The bioreactor is assimilated with the heart of the biotechnological process, being the equipment in which the substrates are converted to the desired products under the microorganisms, cells or enzymes action. This comparison is due to the fact that the bioreactor “aspirates” the nutritive media and the biocatalysts through the upstream routes, “pumping off” the biosynthetic products through the downstream routes [1]. Numerous types of bioreactors are currently used at laboratory or industrial scale. Although the bioreactors with immobilized biocatalysts are derived from the “classical” bioreactors and, therefore, their constructive and functionally characteristics are rather similar with the second ones, the place of bioreactors with immobilized biocatalysts is privileged. The top position is the result of the advantages offered by the use of the immobilized microorganisms, cells or enzymes, namely as: the increase of the thermal, chemical and to the shear forces resistance of the biocatalysts, the increase of the number of the repeated biosynthesis cycles using the same particles of biocatalysts, the easier recovery of the biocatalysts from the final broths, the diminution or avoidance of the inhibition processes.

The bioreactors using immobilized biocatalyst can be designed as column, stirred, airlift or membrane bioreactors.

They are operated in batch, continuous or semicontinuous systems, with fixed, mobile/stirred, expanded or fluidized bed. Among them, the bioreactors with stirred/mobile bed of immobilized biocatalysts are some of the most studied and applied bioreactors, owing to their very similar constructive and operational characteristics to those of the well-known stirred bioreactors. The main difference between the constructions of the two types of bioreactors consists on the presence at the bottom of the former ones of a sieve which avoids the biocatalysts particles washout.

2 BIOREACTORS WITH FIXED BED OF BIOCATALYSTS

In the last decade, the bioreactors with fixed bed of biocatalysts (packed-bed bioreactors) became some of the most used type of bioreactors, because of their low costs of exploitation and maintenance, easiness of scaling-up and of automatic controlling, generation of significant lower shear forces, and, consequently, avoidance of the breakage of biocatalysts particles. The packed-bed bioreactors are used for wastewater treatment, biosorption from wastewater of different metallic ions, solvents and fuels, pharmaceuticals and fine chemicals production.

Sarti et al. (2001) designed a packed-bed tubular bioreactor for wastewater treatment with the biocatalyst bed consisting on the anaerobic activated sludge entrapped into polyurethane foam. The bioreactor is placed horizontally, the ratio between its length and
diameter being of 20. The formed gas is collected through a perforated tube placed on the bioreactor length. The efficiency of this bioreactor is comparable with the classical basin with activated sludge, but its working volume is significant lower and the process parameters can be more precisely controlled and regulated.

The ethanol has been obtained from molasses by yeasts cells entrapped into alginate matrix, and could be used in food/beverage industry or as biofuel. In this purpose, a bioreactor of column type having the immobilized yeasts on a sieve plate has been used. The fermentation can be carried out at higher sugar concentration and at lower pH-value than the process using free yeasts cells. The optimum alginate particles diameter was found to be between 2 and 2.4 mm.

The biocatalyst could be disposed around the stirrer in a fixed bed with cylindrical geometry. This type of bioreactor is known as “basket bioreactor” and is derived from the “catalytic basket reactor”, described for the first time by Carberry in 1964. In the case of ethanol production, the stirred basket bioreactor offers many advantages compared with the conventional stirred bioreactor: it can be operated in batch, fed-batch or continuous flow systems, the productivity is for 4 - 6 times higher (12 g/l.h), more accurate control of the temperature and pH, the stability of biocatalysts allows to repeating the fermentation cycles for over 35 times. The application of this bioreactor could be extended to the treatment of wastewater, especially for recovering the heavy metals from mine drainage [2].

3 TYPES OF “BASKET” BIOREACTORS

“Basket” bioreactor described by Fadnavis et. al. (2007) provides a porous vessel bioreactor apparatus for use in reaction with immobilized enzymes and/or microbial cells. The above-mentioned apparatus consist of a vertically elongated reaction vessel having at least one liquid reactant inlet, at least one product outlet on the vessel, at least one porous vessel completely submerged in the reactant. The porous vessel have pore size ranging from 5 mm to 0.2 microns and a vertical length less than a level of the reactants to be maintained in the vessel, immobilized biocatalysts particles comprising the enzymes and/or microbial cells placed inside the porous vessel such that the liquid reactant is in contact with the biocatalyst in both radial and axial direction. The feed point to the porous vessel can be located at any point along the dimensions of the porous vessel, preferably at either at a top or at a bottom end of the vessel. The invention has the advantage of permitting greater contact between reactants and biocatalyst, which in turn increases the reaction rate and efficiency of the biocatalytic reaction. Another advantage is that the biocatalyst is separated from the reaction mixture simply by draining the circulating liquid [3].
Electrolux bioreactor unit used in this study addresses these problems.

A schematic diagram of one such industrial size three phase bioreactor (1200 l Electrolux) is shown in Fig. 3. As seen, the essential feature of this bioreactor is a conical shape, symmetric basket region located at the center of the fermentor and occupying less than 7% of the total volume.

Air or air/oxygen mixtures are sparged directly into the bottom of the conical basket region. Oxygenated medium flows outwards through the screen to the immobilized cell region which is devoid of bubbles and is gently stirred by a marine type impeller located at the bottom of the conical basket (Fig. 4). The whole screen rotates at the same speed as the impeller. Commercially available Cytodex I microcarrier beads at a loading of 5 g/l are typically used to support the MRC-5 cells. Microcarrier beads do not pass through the screen because the mesh hole size is 80 μm [4].

Measurements of gas–liquid and liquid–solid mass transfer coefficients performed in two types of three-phase laboratory reactor equipped with stationary catalytic basket and multiple impeller were describe by Pitault et al. (2005). Those reactors are called Robinson–Mahoney (RM) reactors [5].

The RM reactors are specifically designed to offer an optimal contact between gas and liquid, and liquid and solid. They consist of a multiple impeller located inside a stationary catalytic basket, which provides the fluid flow through the basket wherein the catalytic pellets are maintained. Even if both reactors use the same concept of stationary catalytic basket, the design differences were important:

- In the Autoclave Engineers reactor, the whole volume is filled with liquid while gas is the dispersed phase. A distributor at the bottom of the tank introduces both phases into the center of the annular basket. A standard six-bladed radial turbine impels the gas bubbles and liquid phase through the basket to the reactor wall. Gas and liquid outlets are at the tank top (Fig. 5).

- In the Parr reactor, the liquid phase fills the two-thirds of the tank volume while the remaining third consists in a gas space. The gas-inducing impeller allows to produce gas bubbles in liquid phase and to flow gas and liquid phases through the basket to the reactor wall. In this reactor, the induced gas flow depends on the local pressure at the exit orifice of the impeller, and on operating parameters such as liquid level or rotation speed (Fig. 6).
In both configurations, the catalytic pellets are only in contact with the liquid phase. Moreover, performed in continuous mode, those reactors allow to test catalysts in larger ranges of weight hourly space velocity (WHSV) and gas to liquid flow ratio than packed bed reactors and allow direct rate measurements very convenient for kinetics estimation too.

The same types of bioreactors were used by Magnico et al. (2006) to investigate more accurately the hydrodynamics of the those two bioreactors by means of CFD in order to compare the effect of the blade/baffle hydrodynamic interaction on the flow pattern [6].

The AE reactor, which has a volume of 0.9 l, was investigated by Mitrovic (2001) (Fig. 7). It has an inner diameter of 8 cm and a height of 18 cm. The fluid is stirred by a six-blade radial-type turbine and a pair of four 45° pitched blade axial-type turbines (Fig. 7a). The diameter of the blades is 3.2 cm. The radial turbine is 5.5 cm high and 0.2 cm thick; the axial turbine is 1 cm high and 0.2 cm thick (Fig. 7b and c). The catalytic basket has an inner diameter and an outer one of 4.25 and 5.75 cm, respectively. The basket height is 9 cm. Two horizontal rings (0.9 cm width) close the top and the bottom of the basket. Two types of baffles fit out the reactor. Four outer baffles (9cm × 0.4cm) are located along the catalytic basket at the outer interface. Four inner baffles (9 cm × 1.6 cm) are inside the basket and in the stirred region. The basket and the turbines are located at 11.4 cm respectively from the top of the reactor. The gas is injected from the bottom of the reactor, but at the top there is no gas/liquid interface [7].

The Parr reactor investigated by Fongarland (2003) has a volume of 300 ml (Fig. 8) [8]. It has a diameter of 6.4 cm and a height of 10 cm. The interface gas/liquid is located at 8.2 cm from the reactor base. The fluid is stirred by a gas inducing turbine which is composed of three 17° pitched blades (Fig. 8a). The blade dimensions are 2.4 cm in diameter, 4.3 cm high and 0.2 cm thick. The gas is transferred to the liquid phase through the shaft by means of two holes located above the gas/liquid interface and at the horizontal plane of symmetry of the blades. The basket has an inner diameter of 3.4 cm, an outer diameter of 5 cm and a height of 5.1 cm. As in the AE reactor, two horizontal rings (0.3 cm width) close the basket. The reactor has two kinds of baffles. Three inner baffles of cylindrical form are located inside the basket and three outer ones are located along the tank wall (5.1 cm height, 4 mm width and 3 mm large). The bottom of the blades and of the basket are located at 3.9 and 1.3 cm, respectively, from the bottom of the reactor.

The simulations reveal in both reactors a ring-shaped vortex around the impeller in the agitation region. The high axial location of its centre induces a reverse flow at the tips of the basket. Owing to the fluid friction in the porous medium, the azimuthal flow in the core region is transformed into a radial flow in the basket where the flow decreases abruptly. Vertical vortices are located at the blade tips and at the
downstream face of the baffles or they are located in the basket on both sides of the baffles, depending on the design and the location of the baffles. At the inner radius interface of the basket, the vertical blade impeller induces a rather homogeneous velocity profile, but the pitched blade impeller imposes a high velocity at the plane of symmetry. Therefore the simulations demonstrate that two different local velocity patterns and two different porous media may induce the same mass transfer properties.

Streptomycin production from chitin by *Streptomyces griseus* was compared by Richard J.L. et. al. (2008) using two different types of bioreactor [9]. One of them was a bioreactor of novel design in which the chitin was contained in a wire mesh basket that was totally submerged in a liquid salts medium (Fig. 9). During operation the chitin was gently fluidised by air admitted into the basket. Fermentation was continued in both bioreactors until maximum antibiotic titres were achieved whereupon operation was interrupted to allow the streptomycin adsorbed to the chitin substrate to be extracted into pH 3.0 buffer before continuing fermentation of the same batch of chitin a second time. At a chitin concentration of 10% (w/v) the highest streptomycin yields (cca. 5.5 mg/l) were obtained using the stirred bioreactor, however, growth occurred faster in the vertical basket bioreactor.

Sheelu et.al (2008) report immobilization of *Lecitase* in a gelatin hydrogel matrix crosslinked with glutaraldehyde [10]. The immobilization matrix is quite cheap and biocompatible, the immobilized enzyme is found to be thermally stable and can be used several times for degumming of rice bran oil. A spinning basket reactor is found to be highly effective in overcoming the problems of attrition of the gel and separation of the immobilized enzyme from the oil (Fig.10).

![Fig. 9 Vertical basket bioreactor](image)

**Fig. 9 Vertical basket bioreactor**

The porous catalytic basket is made of stainless steel. The solid catalyst particles (diameter 1–2 mm) are packed loosely in the basket which is rotated in the jacketed vessel containing crude rice bran oil. Samples are collected at 30-min intervals, treated with bleaching earth and activated charcoal, dewaxed and analyzed for their phosphorus content. In a single operation under optimum conditions, the phosphorus content of the rice bran oil decreases from 400 ppm to 50–70 ppm in 2 h. Increasing the speed of the impeller from 50 to 400 rpm shows that the reaction rate increases with impeller speed and between 350 and 400 rpm reaches a constant value.

**4 CONCLUSIONS**

In the last decade, the bioreactors with fixed bed of biocatalysts (packed-bed bioreactors) became some of the most used type of bioreactors and among them the basket ones seems to be one of the most promising bioreactors in a large field of the chemical engineering: wastewater treatment, biosorption from wastewater of different metallic ions, solvents and fuels, pharmaceuticals and chemicals production.

**References**


